PMT Pulse-Shape Analysis by Using A Convolutional Neutral Network in Nuclear Radiation Detection

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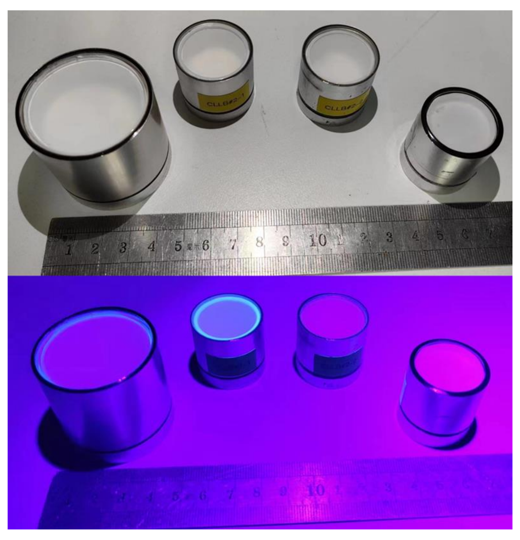
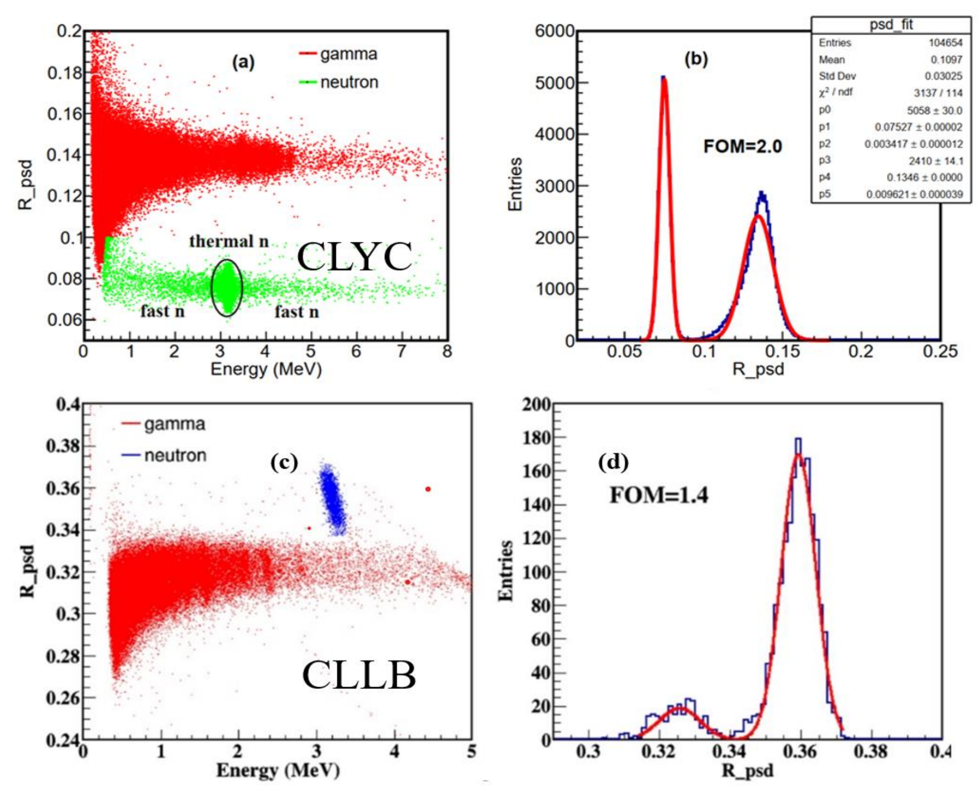
Introduction

Abstract: Cs_2LiYCl_6 (CLYC) and $Cs_2LiLaBr_6$ (CLLB) scintillators have n/g discrimination capability. Figure-of-Merit (FOM) value was optimized to 2.0 for CLYC, 1.4 for CLLB by using the charge comparison method (CCM). The neutron and gamma waveforms measured by CLYC and CLLB scintillators coupled PMT under Am-Be source irradiation based on the Convolutional Neural Network (CNN) method and the FOM value of the CNN method was better than 8.0. In addition, we constructed CNN model for complicated n/g discrimination under piled-up condition with a model accuracy of 99%. With the development of fast analog-to-digital converter, the whole waveform information could be available. Compared with the traditional Constant Fraction Discrimination (CFD) timing method, a new one based on the CNN model for the timing of a pair of Cherenkov-detection MCP-PMTs improves the coincidence time resolution (CTR) by 50%.

1. The charge comparison method for the n/g discrimination

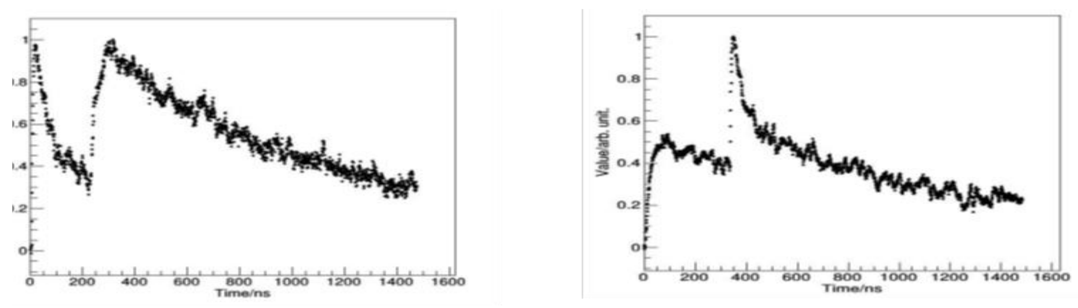


Packaged CLYC and CLLB scintillators

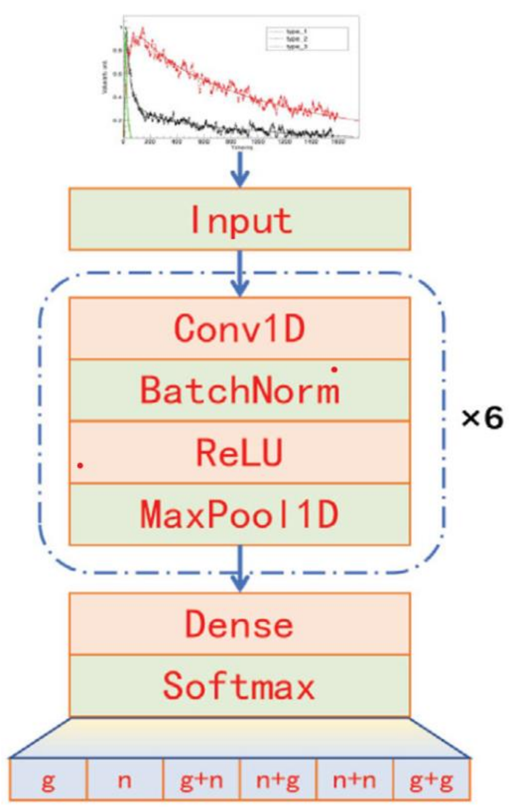


- **The PSD scatter plot (a) and 1D PSD histogram plot (b) for CLYC under Am-Be source.**
- **The PSD scatter plot (c) and 1D PSD histogram plot (d) for CLLB under Am-Be source.**
- **The neutron-gamma discrimination of CLLB scintillator is worse than that of CLYC, and the conventional charge integration method may not be good for neutron-gamma discrimination of CLLB scintillator.**

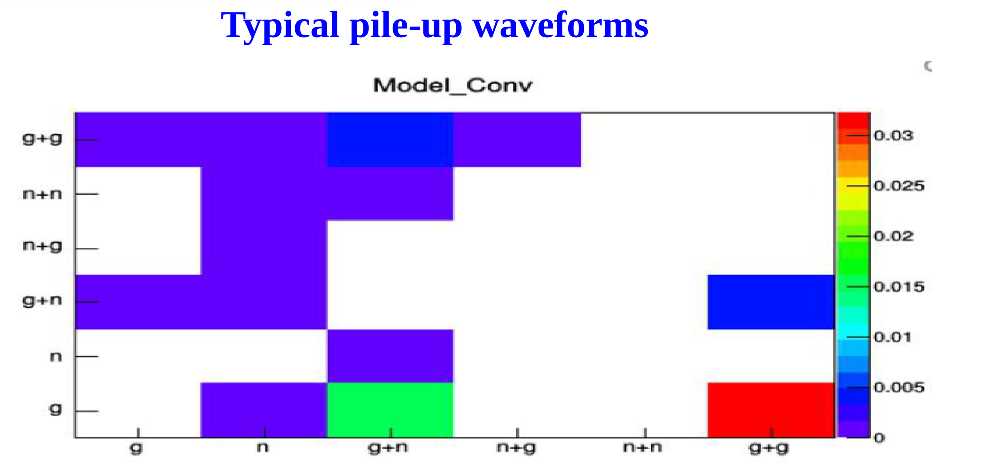
3. The CNN method for piled-up condition



Typical pile-up waveforms



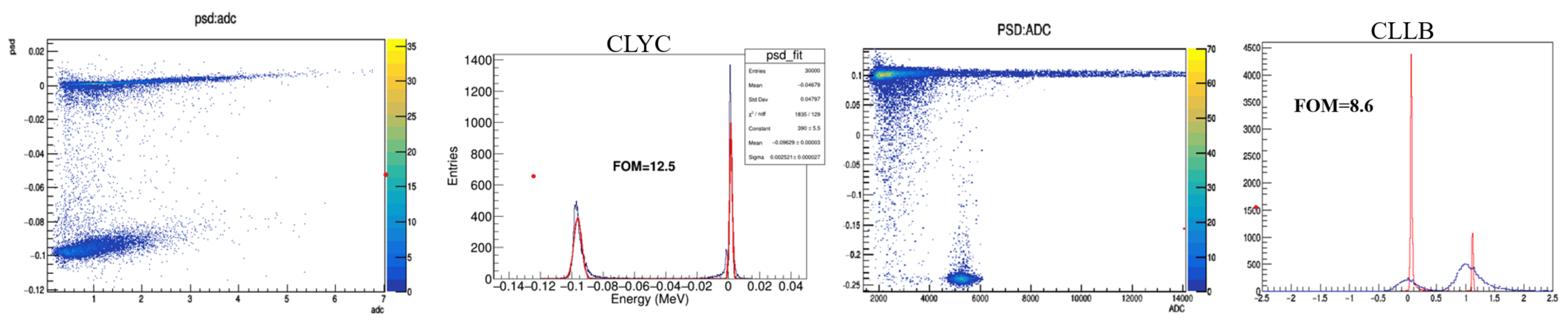
The CNN structure



	g+n	n+g	n+n	g+g
accuracy	98%	100%	100%	96.4%

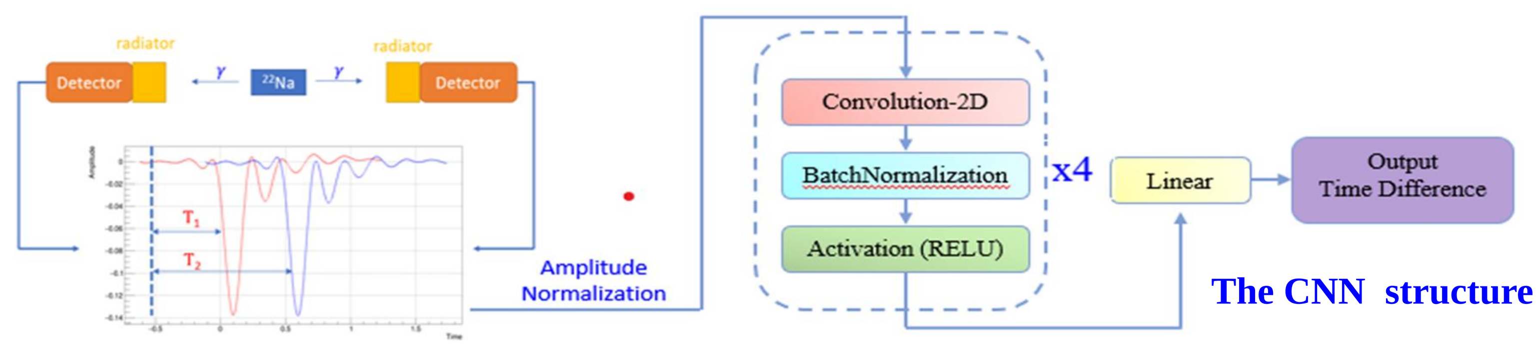
- **Artificially piled-up pulses are generated by adding single pulses, each of which is given a corresponding label.**
- **Complex discrimination of piled-up pulses using CNN with an overall accuracy of 99%**

2. The CNN method for the n/g discrimination

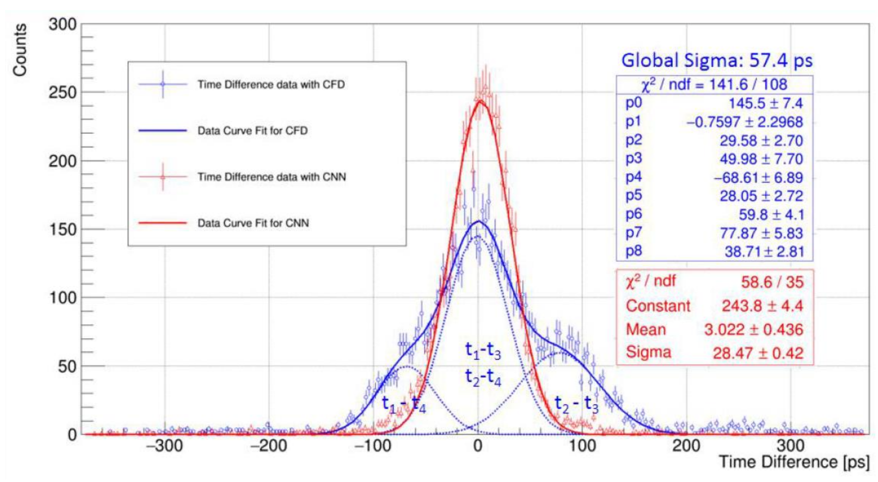


- **The 2D PSD distribution and 1D PSD distribution under Am-Be source by CNN method**
- **The neutron and gamma signals obtained by the charge comparison method are labeled correspondingly and used for CNN model training.**
- **For CLYC scintillator, the FOM value of the CNN method was 12.5, while CLLB scintillator was 8.6. The CNN method has obvious advantages in particle discrimination, and the FOM value of the CNN method was better than 8.0.**

4. The CNN method for waveform time analysis



The CNN structure



Global Sigma: 57.4 ps, CNN Sigma:28.5 ps

- **The time information carried by the PMT waveform is important when reconstructing the particle trajectory especially in the application of TOF detectors.**
- **The timing resolution: CNN model is 50% smaller than traditional CFD method, which helps to improve the spatial resolution of PET**

5. Conclusions

- **The CLYC had excellent discrimination ability between neutron and gamma with the Figure of Merit (FOM) value better than 2.0, Unlike CLYC, CLLB was only sensitive to thermal neutrons, and the discrimination ability between neutrons and gamma rays is worse than CLYC, whose FOM value is 1.4.**
- **The neutron-gamma discrimination by the CNN model is significantly better than the conventional charge comparison method method, and the FOM value is improved by a factor of 6 compared to that of charge comparison method.**
- **The CNN model has good accuracy for the complicated discrimination of piled-up pulses, and the accuracy of particle discrimination exceeds 97% for each class (g+g, g+n, n+g, and n+n) for complicated n-g discrimination in the piled-up condition, indicating that the CNN model is suitable for complicated neutron-gamma discrimination under high counting rates.**
- **The CNN model developed successfully improved the coincidence time resolution (Sigma) for a pair of Cherenkov-detection FPMTs from 57.4 ps to 28.5 ps. This proves the ability for the CNN model to extract features from the PMT waveforms and realized a more accurate and precise measurement on the time information**

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